§12. Simulation Study of Zonal Flow Generation with a Classic 2D Fluid Model and Comparison with Linear Predictions

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The generation mechanism of zonal flow is studied using a 2D classic drift wave model involving the Hasegawa-Wakatani (H-W) equation [1].

First we consider 2D model by fixing the value of the parallel wave number. The average energy of ExB flow in x and y directions are shown in Fig.1. Here the definition of y average is $V_{y0}=<V_y>_y$, and x direction corresponds to the radial direction, and y direction corresponds to the poloidal direction. There is no clear difference of energy in x and y direction. Thus in this case, the system is in the quasi steady state without average flow.

Next, a modification associated with the periodic boundary condition along the field line [2] is considered for the 2D H-W. Just after the linear phase, large-scale zonal flow (ZF) can be generated gradually as in Fig.2. ZF is generated continuously in this case, but the system does not reach the steady state in the time scale considered.

To obtain a quasi-steady state with zonal flow, we approximately include the effect of the curvature of the magnetic field line in the 2D system. This model can describe the coupling between zonal flow and the geodesic acoustic mode (GAM), which is observed in 3D simulations [3]. The result is shown in Fig.3. The zonal flow is generated but it is reduced by the GAM, and as a result, the system can reach the quasi steady state.

In summary, in the system described with the approximations used in Hasegawa-Wakatani model, the zonal flow is generated by the small scale fluctuations due to the drift wave instabilities. This generation due to the Reynolds stress occurs slowly as a result of integral effect of fast and small scale fluctuations. Once large scale zonal flow is generated, it cannot be dissipated with the viscosity, so that the system does not reach the steady state. The only dynamic coupling between the large-scale zonal flow and GAM can make the system quasi steady state.

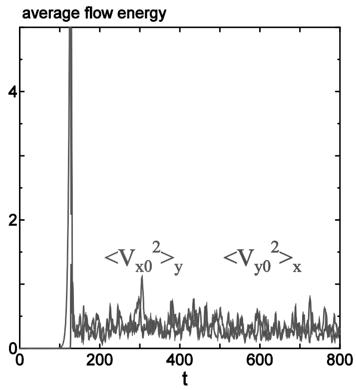

Figure 1: 2D original H-W

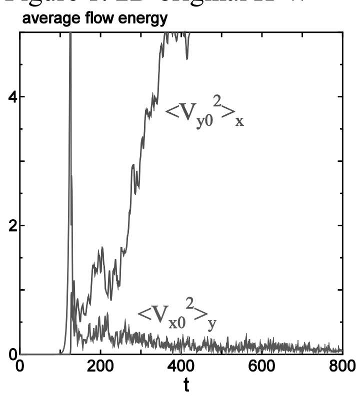

Figure 2: H-W modified on ZF

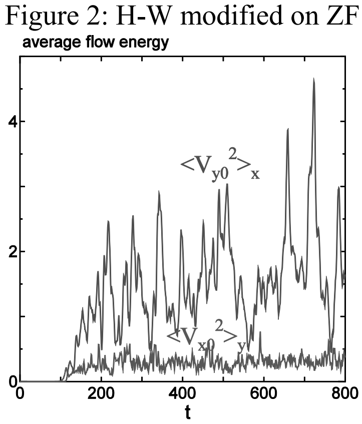

Figure 3: H-W modified on ZF and curvature

1) A.Hasegawa and M.Wakatani, Phys. Rev. Lett. **50**, 682–686
2) B.Scott, *New J. Phys.* **7** (March 2005) 92
3) N.Miyato, J.Q. Li and Y. Kishimoto, *Nucl. Fusion* **45** No 6 (June 2005) 425-430